Practical Demagnetization of Large Steel Plates

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June 30, 2003

Abstract

We report on an attempt to smooth out the magnetization in a set of large ($\sim$40 sq. ft., 1 in. thick) steel plates. We describe the construction and operation of a "magnetic circuit," built so that several plates could be degaussed without repeating the laborious winding of the coils. The most successful method used a DC power source to spiral into the center of the hysteresis curve. We successfully removed localized magnetic features, and the residual field above the plates after the process was uniform to within about one gauss.

1 Introduction

The target cave being built for the NPDγ experiment, under construction at LANSCE, contains a spin flipper which is sensitive to magnetic field anisotropies of only a few milligauss over its volume. Magnetic shielding was an important consideration in the design of this experiment. The first line of defense is the cave itself: the target is entirely enclosed in steel, to act as a flux return for the magnets around the spin flipper and to shield against stray fields from the large superconducting magnet on the next flight path.

The floor of the cave, which is presently assembled, consists of eight irregularly shaped plates of A36 steel, each roughly $8' \times 5' \times 1''$. These plates were delivered with complicated magnetizations, most prominently due to their initial placement at the beamline with a crane magnet. Our task was to alter the magnetization of the plates so that the field a few inches above the surface was uniform over the plate at the level of about 500 mG.

2 Theoretical Motivation

Ferromagnets contain microscopic domains with nearly perfect magnetization. In a ground-state ferromagnet these domains are randomly oriented, but exposure to a magnetic field aligns the domains somewhat and leaves the material magnetized. Removing this macroscopic magnetization requires putting enough energy into the material to rattle the atoms and permit the microscopic domains to re-randomize.

The most obvious way to supply this energy is to heat the material above its Curie point. However, baking several unwieldy tons of steel to 800^oC presents its own set of technical challenges and was not seriously considered. We excluded mechanical shock for similar reasons: an impact powerful enough to supply the Curie energy would likely also shatter the plate. (Banging the plate with a sledgehammer had no measurable effect.)

We supplied the energy by applying a strong, alternating magnetic field. After saturating the material in opposite directions and then gradually reducing the peak field strength, fewer domains should flip over on each reversal. A careful reduction to zero applied field would then reduce the residual magnetization to zero. We attempted to implement this idea in several ways, with varying success.

To make better use of our magnetic energy we constructed a complete magnetic circuit, in which the field lines could follow a path through steel both inside and outside the solenoid. By returning the flux through a second plate, we ensured that the field actually traveled through the metal rather than spilling out uselessly into the air and affecting nearby materials. In addition the magnetic circuit permitted us to degauss several plates while only wrapping one set of coils. This technique was suggested after a degaussing attempt with an external coil proved completely ineffective.

3 Apparatus

The magnetic circuit was constructed by coiling wire around one plate, setting scrap metal on its ends, and putting the plate to be demagnetized on top of the scrap metal. The scraps held the plates roughly six inches apart.

Not all of the plates we degaussed were the same size. The larger ones overhung the base; these we positioned so that the overhanging end (which is outside the magnetic circuit and has a larger residual field) will be farthest from the final experiment. We also degaussed three steel covers for the utility trench that will run under the cave. These were only slightly wider than our layer of coils; the scrap metal was moved to support them. These setups are illustrated in the first two figures.

The coils were made of roughly 900 feet of cable wound in a single layer 77 times. The cable contained six #18-gauge conductors, which were connected so that current passed through two conductors in parallel, three times around the coils. The total resistance was 8–10 Ω, depending on the temperature.

Wrapping the coils presented its own challenge. To avoid having to push the entire unwound length of cable under the plate, the coils were wound by lifting one end of the plate with a crane and wrapping the coils in five layers beyond the lifting hole. The degausser initially ran with the coils in this asymmetric arrangement, but its effectiveness was asymmetric also. The single layer illustrated is located entirely between the two lifting holes.

The circuit was powered in two different ways. Initially the power source

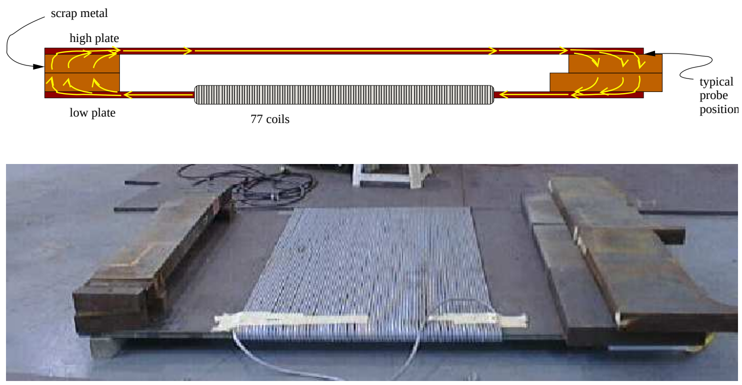

Figure 1: Degausser setup cartoon and photo. The magnetic circuit is suggested in the cartoon. Top plate removed in photo.

was a bipolar, 40 V, 10 A power supply which could be controlled by a function generator. However, this current was not adequate to saturate the steel, and better results were achieved with a unipolar power supply capable of 250 V. The maximum current put through the coils was about 28 A.

4 Method

4.1 Measurements

We performed two types of magnetic field measurement: of the residual field above the plates with no current, and of the field between two of the pieces in the magnetic circuit.

A triple-axis Hall-probe gaussmeter reported the field above the plates. The gaussmeter probe sat on top of a two-inch polyurethane block. A one-foot grid marked on the surface of each plate provided a way to position the probe reproducibly: placing one corner of the block on each mark put the probe tip at the same point above the plate to less than a centimeter in all directions. These measurements produced the field maps discussed below. The uncertainty in each component, due mostly to zero drift, was roughly 20 mG.

Later residual-field measurements between runs on the degausser were taken with the upper plate removed from the base, roughly ten feet away. No individual piece of metal in the apparatus achieved zero magnetization, but their magnetizations tended to cancel out to produce a uniform field above the intact degausser. This masked anisotropies in the upper plate, particularly near the ends. Field maps presented in the analysis section which were taken on an intact degausser are marked as such.

For the hysteresis measurements we desired a closer approximation to the field inside of the metal than could be obtained from above or between the

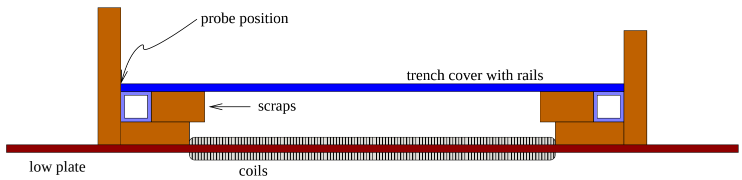

Figure 2: Degaussing a trench cover. The important part is the metal plate on top of the cover, not the hollow rails around its base; the four-inch blocks used to make a better magnetic contact inside the rails are shown in the cross section.

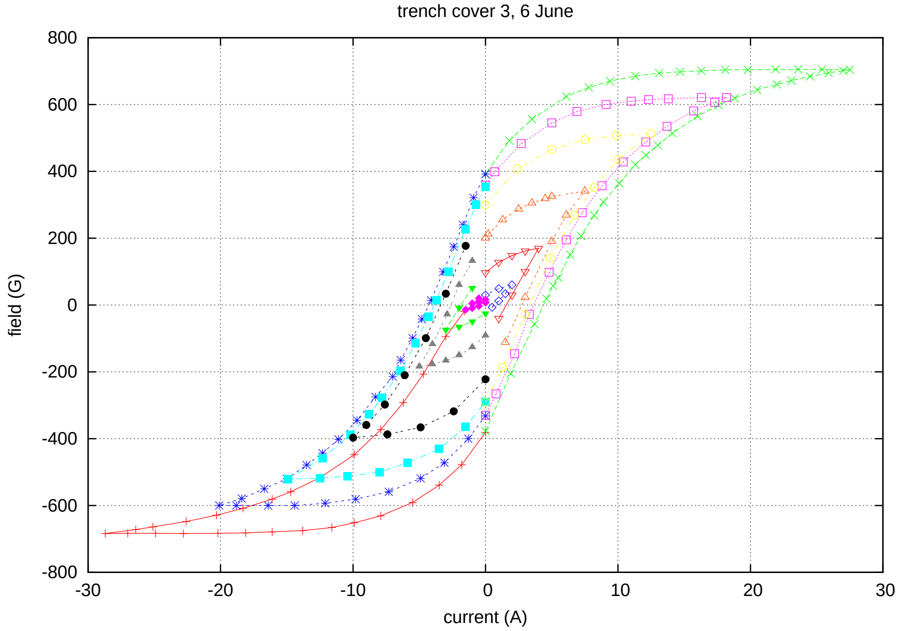

Figure 3: Walking around the hysteresis loop for a trench cover. Changing polarity on the power supply is represented by changing symbols. The magnetization began near zero, was negatively saturated, and spiraled back near zero.

plates. Typically the scrap metal and the upper plate made imperfect contact (e.g. at the blocks on the near left corner in the photograph). A thin Hall probe could be inserted into the crack; this probe measured field strengths an order of magnitude higher than the leakage field accessible with the triple-axis meter.

4.2 Degaussing Algorithm

The traditional method of degaussing small magnetized objects, such as tools or CRT screens, employs a solenoid powered by 60 Hz mains. The solenoid is brought near and slowly removed from the object to be degaussed, or the current amplitude is slowly ramped up and down with a variac. The variac was not an option in our case, since the skin depth of steel at 60 Hz is roughly 1 mm, and initial attempts to demagnetize the plates with an external coil had essentially no effect. However, the idea of a gradually reduced oscillating field guided our program.

The first power supply we used was capable of bipolar output and offered a function generator input. We used it to generate a sinusoidal current at a half to a few hertz, ramping it on and off over many cycles. This is referred to as “AC degaussing.” It was not terribly effective; whether this is because the current was not strong enough, the frequency too high, or some combination of these factors is not clear.

The second power supply was capable of producing much stronger currents, but was unipolar; changing the current direction required switching two alligator clips on the back of the supply. The most effective use of this power supply was to walk around the hysteresis loop: push as much current as possible through initially and reduce the peak current by about 10% each reversal. The stopping point was when a reverse current was too small to change the sign of the residual magnetization, typically less than an ampere.

These two methods were also tried in combination. The large power supply would be used to saturate the material and walk down the hysteresis loop into the range of the smaller; then the smaller supply would be used as a slow oscillator to ramp the amplitude the rest of the way down to zero. Alternatively, instead of decreasing the current amplitude we could gradually increase the frequency up to a few hundred hertz, where the skin depth of steel is effectively zero, reducing the field in the metal that way. These mixed methods left more irregular magnetizations in the plates than the purely DC method described above.

5 Results

The initial degausser was built of identically-sized plates, labeled C (top) and D (bottom). We analyzed the effects of the different degaussing methods on plate C. This section presents the field above plate C after each important change in the apparatus, with descriptions of the changes and of particularly striking features.

Figure 4 shows the initial residual field above plate C. The effect of the crane magnet is clearest in the third component, and is also obvious in the full-strength field. Figure 5 shows the field two days later, after degaussing attempts with the smaller, bipolar power supply at various frequencies (0.5–5 Hz) for various lengths of time. This had smoothed the field somewhat but was still deemed unsatisfactory.

At this point we added the larger power supply. Pushing a larger current (28 A maximum) had a much larger effect on the residual magnetization of the plate, but still it had undesirable features: the field was large at the plate edges, and the asymmetry in the coil winding was quite obvious. This is shown in Figure 6. In addition, we discovered that the small observed residual field was a property of the intact degausser and not of the top or bottom plates individually; reversing the direction of the upper plate gave a variation in one component of nearly ten gauss. Degaussing the reversed plate largely restored the smaller, more uniform field of Figure 6. This demonstrated that our magnetic circuit was in fact able to reduce the residual magnetization in the plates, just not to the degree that we had initially hoped.

From this point onward the plates were mapped off of the degausser. In addition, the coils were spread into a single layer covering much more of the

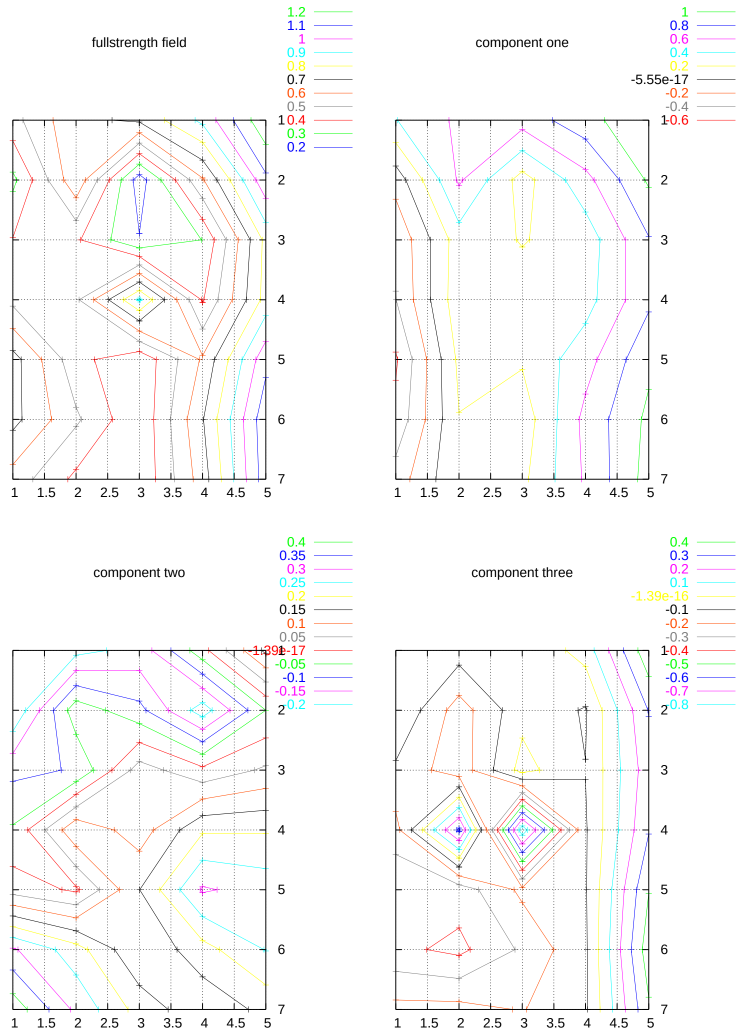

Figure 4: The initial magnetic field of Plate C. All three components and the full-strength field are presented. The displayed contours are straight lines between data points on integer grid intersections. The unit of field strength is gauss; data points are reliable to roughly twenty milligauss. Components two and three, lower row, are horizontal; component one, upper right, is vertical. These conventions are also followed in the other diagrams. This map was made 28 May.

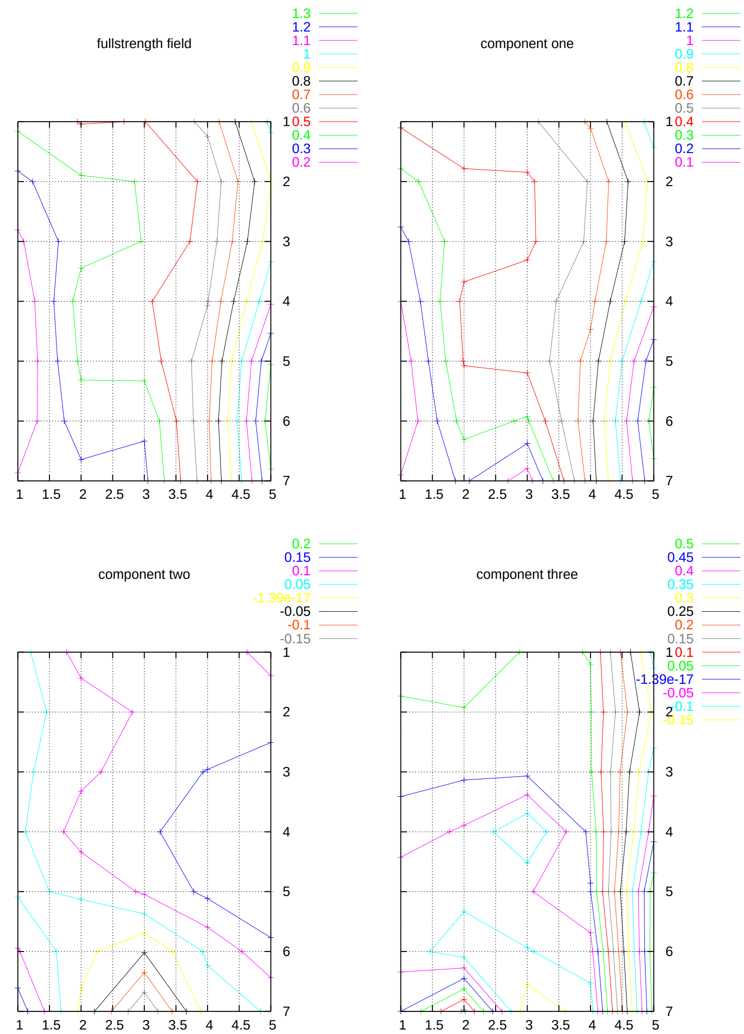

Figure 5: Plate C after 10 A maximum current AC degaussing. Notice the steady increase in residual magnetization toward the right side and the still-visible effect of the crane magnet in component three. This map was made 30 May from on top of the degausser; this residual field includes effects from the bottom plate.

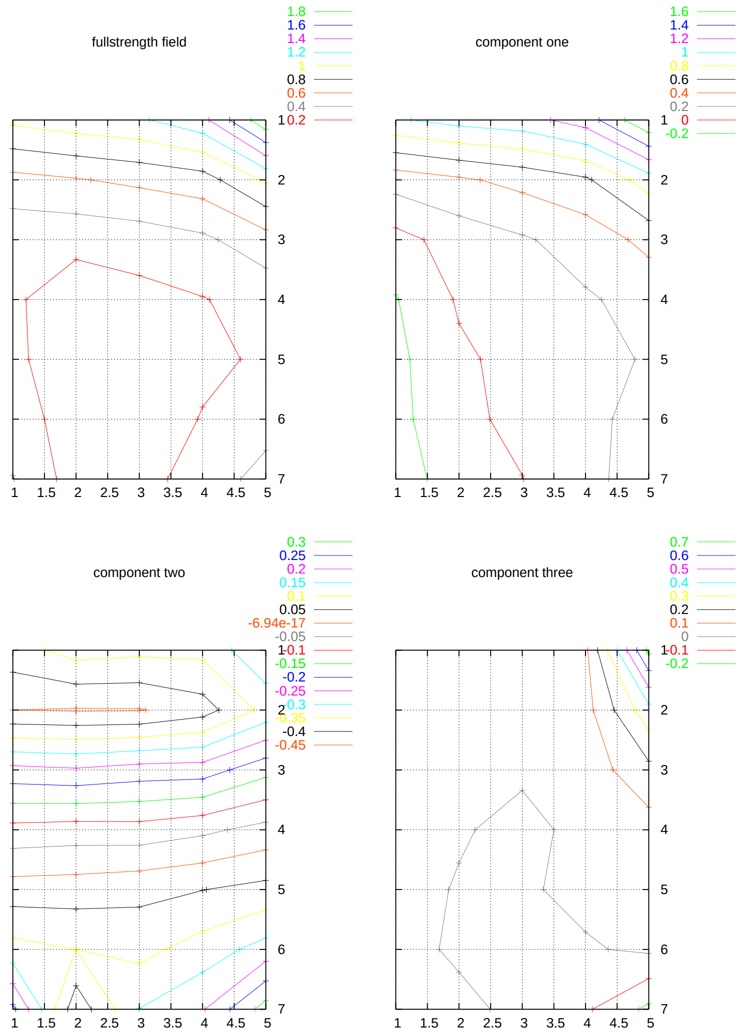

Figure 6: Plate C after using the DC power supply. Notice the spike in the field at the upper right corner, and the profile of the asymmetric coils in component two. Made 30 May from on top of the degausser.

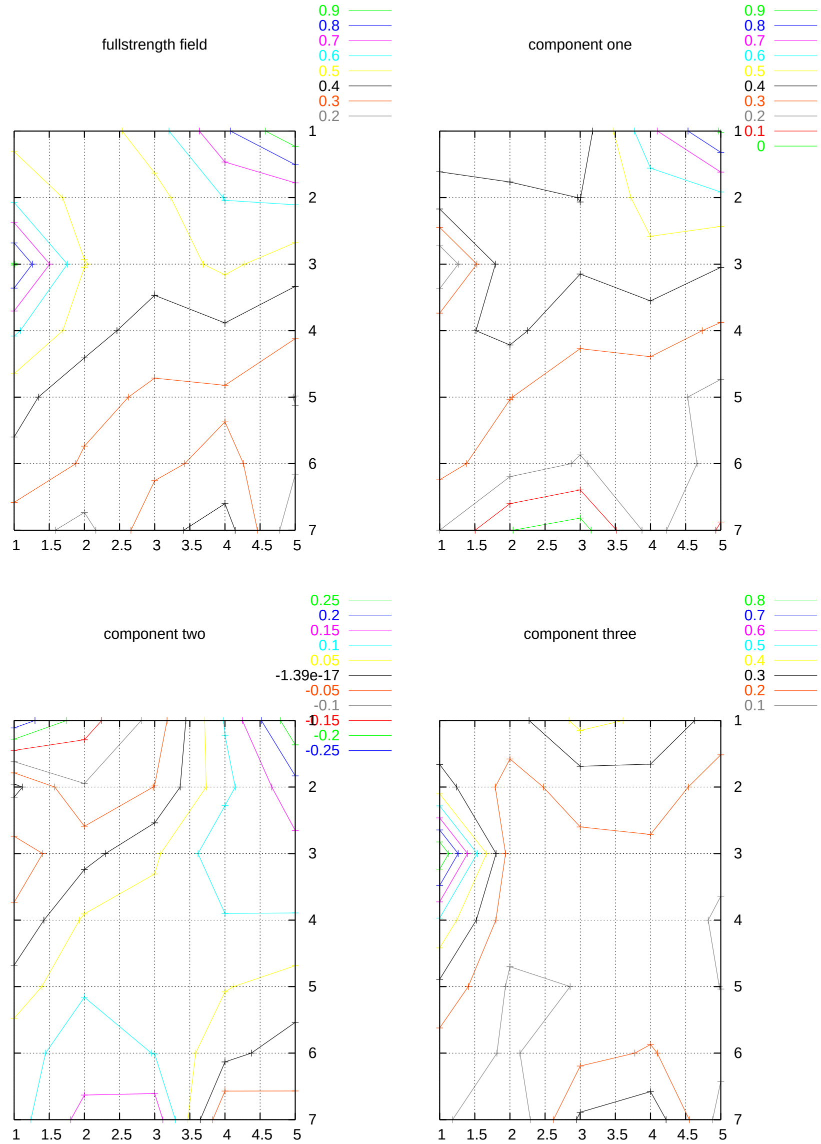

Figure 7: The final magnetic field of Plate C. This map does not suffer from interference from the degausser. Taken 9 June.

lower plate. All subsequent attempts at demagnetization used the large power supply in some capacity, either alone or with the bipolar supply as described above. The final residual field above plate C is shown in Figure 7.

6 Discussion

The largest hurdle in degaussing steel piece of this size was the prohibitively large field needed to saturate the metal. This necessitated the large power supply, which dissipated a lot of heat through our apparatus and still did not entirely saturate the metal. Perhaps better would have been some sort of capacitive discharge to produce large transient currents, or an RLC oscillator, but time and budget constraints precluded designing or building one of these.

It is interesting that such significant differences remained between the AC and DC current sources, even in regimes when they should have behaved identically. The most probable explanation is that the frequency of the AC source was faster than the response time of the system; while walking the steepest part of the hysteresis curve, the field inside the plate sometimes took two to three seconds to respond to small changes in current.

Because the degaussing process was so labor-intensive and unpredictable, we elected not to degauss all the plates on the base of the cave but focus our effort on those with the most impact on the target area. One plate was flipped upside-down to correct a bow; we discovered that its magnetization on the bottom was much more uniform than it had been on the top and did nothing further to it.

We were able to reduce the magnitude and anisotropy of the residual magnetization in several large steel plates by building a complete magnetic circuit and walking very slowly around its hysteresis loop with a high-current power source. We found this to be the most effective of the several methods we have described, producing field uniformity adequate to conduct the NPDγ experiment.